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WADD TECHNICAL REPORT 61-55
PART I

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FINAL DESIGN ANALYSES OF AF 205F-272

PART I: PROPELLER AT TIME OF FIRST RUN

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ALLISON DIVISION
GENERAL MOTORS CORPORATION
INDIANAPOLIS, INDIANA

ENGINEERING DEPARTMENT REPORT NO. 1943

31 JANUARY 1961

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FINAL DESIGN ANALYSES OF AF 205F-272

PART I: PROPELLER AT TIME OF FIRST RUN

Allison Division
General Motors Corporation

Report EDR 1943

31 January 1961

Airborne Support Systems Engineering Division
Directorate of Systems Engineering
AMC Aeronautical Systems Center Contract No. AF 33(600)-39928
Project No. 3138
Task No. 30548

27

Wright Air Development Division
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by Allison Division of General Motors Corporation, Indianapolis, Indiana, on AMC Aeronautical Systems Center Contract No. AF 33(600)-39928, Project No. 3138, Task No. 30548, "Development of Propeller for T63-A-1 Turbine Engine." The work was administered under the direction of Airborne Support Systems Engineering Division, Wright Air Development Division. Mr. Wilbur Carl is task engineer for WADD.

This report is submitted in partial fulfillment of the requirements of WADD Contract No. AF 33(600)-39928, reference Exhibit "1," Phase I, Item 3, part (f).

ABSTRACT

Presented herein are design analyses, propeller description, structural analysis (including performance considerations), aerodynamic design analysis, and a weight breakdown of the AF 205F-272 propeller configuration at the time of the first run.

This report is intended to present information which will lend itself directly to the final design configuration of a controllable pitch propeller, as prescribed in the subject contract.

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LIST OF SYMBOLS

Term or Symbol	Definition	Units
b; chord	blade width at any station	inches
C_L	operating section lift coefficient	--
C_D	operating section drag coefficient	--
C_{L_i}	blade section design camber	--
h/b; thickness ratio	ratio of maximum section thickness to chord length at any station	--
IAS	indicated airspeed	knots
Int. C_{L_i}	integrated blade section design camber	--
J; Advance ratio	ratio of the local velocity to the product of (rps) (propeller diameter)	--
Kn	velocity in knots	knots
L/D	Section lift/drag ratio	--
M; Mach number	ratio of local velocity to local speed of sound	--
r	radius—distance from the propeller shaft axis to any station	inches
R	total propeller radius	inches
r/R	ratio of station radius to total blade radius	--
rpm	revolutions per minute (propeller or engine as designated)	rev/min
rps	revolutions per second	rev/sec
SHP; Shaft Horse-power	Horsepower delivered to the propeller shaft by the engine	horsepower
TAS	true airspeed	knots
Thrust	propeller thrust	pounds
V_L/V_o	ratio of the local velocity in the propeller plane to the free stream velocity	--
β; pitch distribution	relative angular placement of any blade station	degrees
η	propeller efficiency	percent

I. SUMMARY OF PROPELLER RESPONSE AT THE TIME OF THE FIRST RUN

The first run of an Aeroproducts AF205F-272 propeller on an Allison YT63-A-1 turboprop engine was made on 25 August 1960. At the suggestion of Allison personnel, the low pitch stop was adjusted down from 14° to 11° prior to the run because the 14° blade angle would cause an excessively hot start. An 11° low pitch stop setting, according to previous calculations, was the minimum blade angle at which the counterweights and spring could create sufficient force to move the blades off the low pitch stop. This proved to be close since a decrease pitch pressure of only 20-30 psi was required to hold blade angle.

The turbine speed was eased up to governing power as slowly as possible. A propeller speed of 1580 rpm was arbitrarily selected. Governing could be established but was upset by even the slightest transition. Propeller response characteristics are shown in Figure 1. Other governing speeds and power settings were selected but the same extreme slowness of transition was necessary to prevent the governor from "hunting."

An examination of the data shown in Figure 1 discloses that the pitch change rate is too high, particularly for small off-speeds. By reducing the pitch change rate, especially in the area where the governor approaches the on-speed condition, the governor could not overshoot and thereby start "hunting." There is also evidence that the governor piston does not readily lift off the governor cylinder when the governing rpm is reached. This can possibly be remedied by reducing the contact area between the piston head and the end of the cylinder. These changes can easily be made before the next run.

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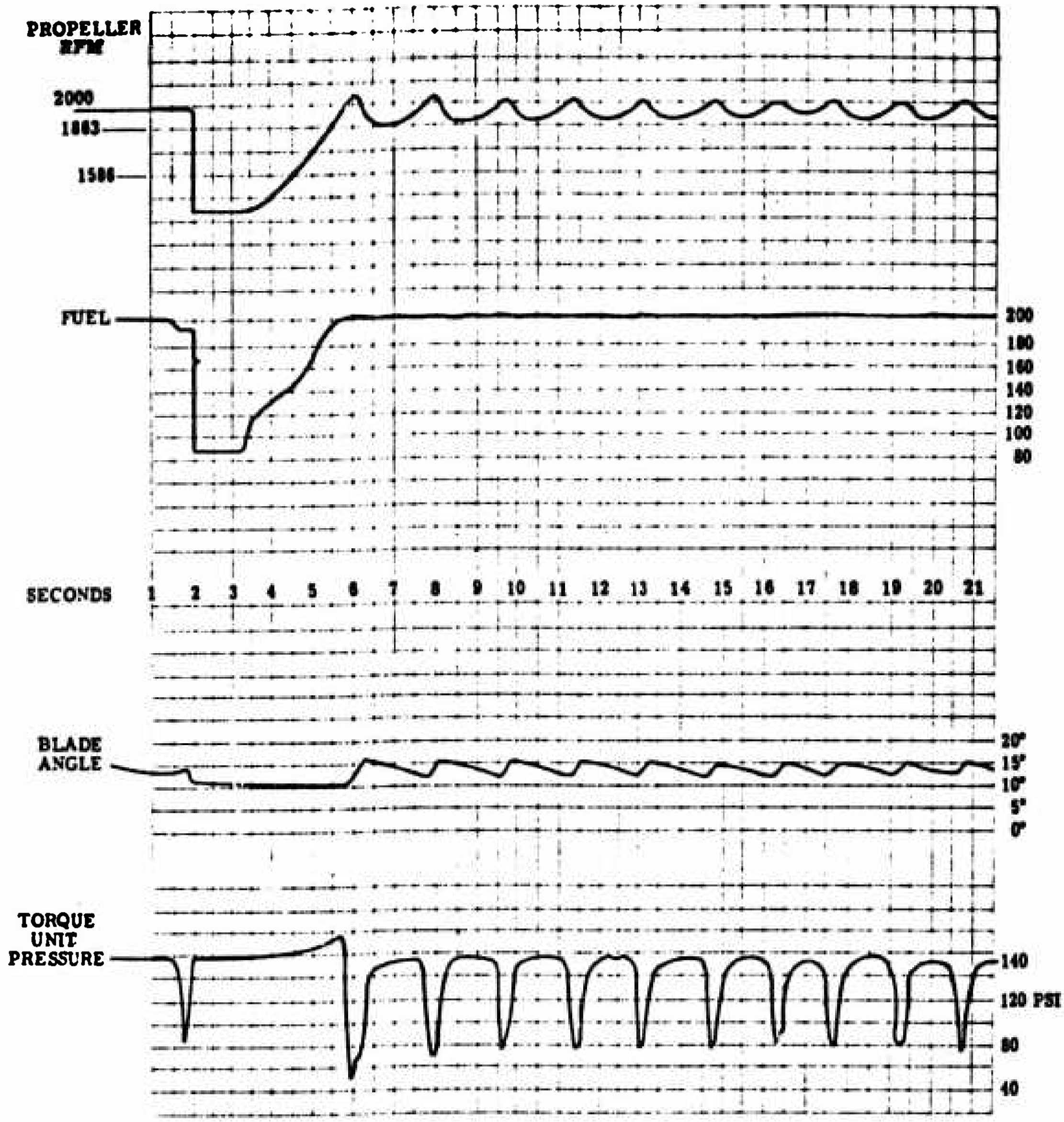

Figure 1. Typical Surging or "Hunting" Conditions Existing on Initial Runs

II. PROPELLER DESCRIPTION

The AF 205F-272 propeller, of the constant-speed, full-feathering type, is a single acting unit in which hydraulic pressure and the natural, centrifugal twisting moment of the rotating blades toward decrease pitch oppose the forces of a spring and counterweight to obtain the correct pitch for the engine load. The propeller, with its spinner, is flange-mounted on the front of the gearbox and is coupled through a shaft to the control unit mounted on the rear of the gearbox. The shaft rotates with the propeller and drives the pump and the governor flyweights, which are located in the control. The shaft also transfers axial motion from the control piston to the pitch change yoke in the propeller.

PROPELLER

The propeller and control are shown in Figures 2 and 3. Instrumentation for the run consisted of a blade angle indicator and pressure take-off pad. The blade angle indicator was attached to the retainer and spring assembly and connected to the recorder through the deicing slip rings brush block. The pressure take-off was made at the auxiliary pump and motor assembly (see Figure 4).

A list of the leading particulars concerning the propeller is given in Table 1.

PRINCIPLES OF OPERATION

The pitch change mechanism has an inherent tendency toward increased pitch because of the spring force applied to the yoke and the counterweight force acting on the blades. A propeller schematic is shown in Figure 4. To change pitch, then, it is necessary to pressurize the decrease pitch side of the piston in the control unit. This pressure is supplied by the pump

TABLE 1
Model AF 205F-272 Data

Number of blades	2	Propeller RPM	
Mounting Flange	SAE, ARP-502	Take-off	2057
Diameter	7-ft 6-in.	Hydraulic Fluid	MIL-L-7808
Take-off Shaft Horsepower	250	Lubricant	Aeroproducts Specification
Rotation (viewed from downstream)	Clockwise		No. 1-43002
Total Weight (dry)	92.00 pounds	Fluid Capacity	1 pint
Total Weight (wet)	93.25 pounds	Pitch Change Rate	10 degrees per second
Blade Angle at 34-inch Station			
Low	11 degrees		

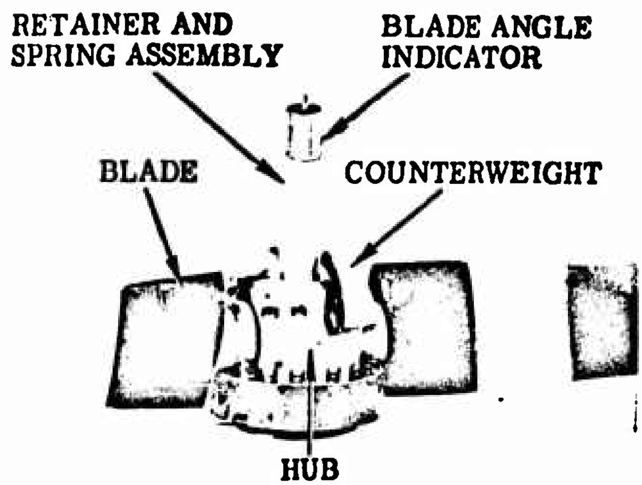

Figure 2. Propeller Assembly

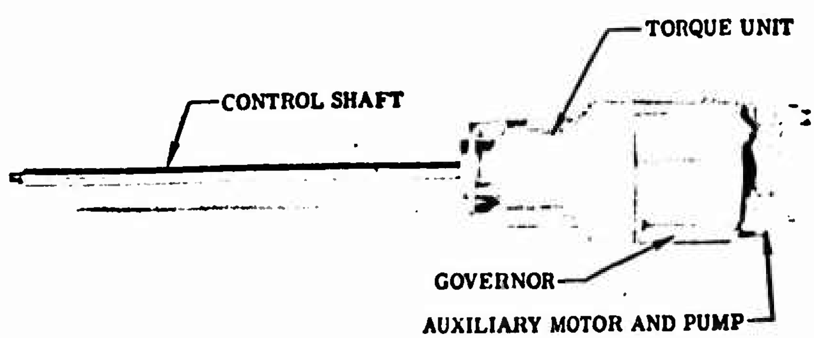

Figure 3. Control Assembly

through the governor and is maintained at the desired pressure by the pressure control valve. Should pressure fail, the control piston will move in the increase pitch direction until it contacts the cruise stop. Then the propeller will operate as a fixed pitch propeller. An overspeed governor provides an rpm slightly above the governor maximum control speed and prevents overspeeding, should the governor fail in the decrease pitch direction. When the propeller is feathering, the pump output is bypassed to drain. The electric motor and pump assembly is used during checkout and may be used for unfeathering the propeller in flight.

ELECTRICAL SYSTEM

The electrical system consists of a 28 volt dc operated auxiliary pump and motor assembly and a 28 volt dc ice control system (see Figure 5).

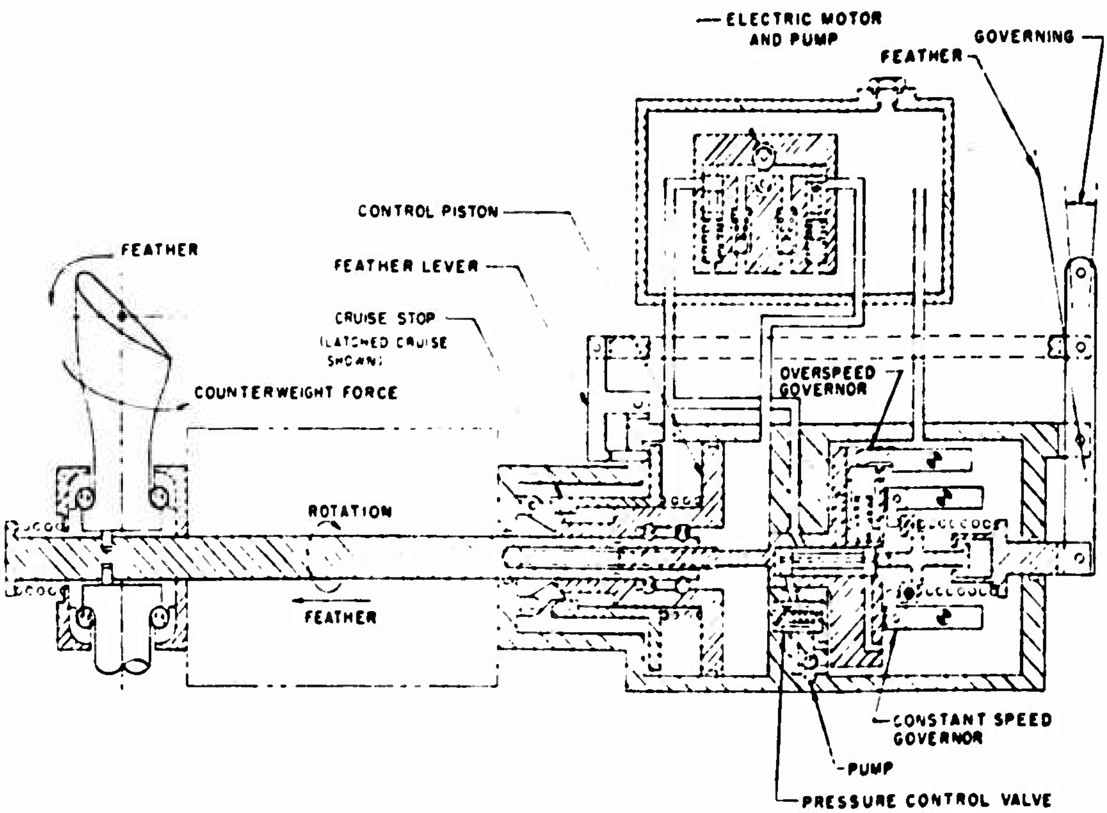

Figure 4. AF 205F-272 Propeller Schematic

The auxiliary pump and motor assembly is used for static checks of the control assembly. This pump and motor assembly is reversible. Operation in one direction increases pitch and in the other decreases pitch.

The single phase cyclic ice control for twin-engine installations consists of four circuits—two for each propeller. Current to the four circuits is controlled by four relays which are actuated in sequence by a deicing timer. The timer has a duty cycle of 25 percent (30 seconds on and 90 seconds off for each circuit).

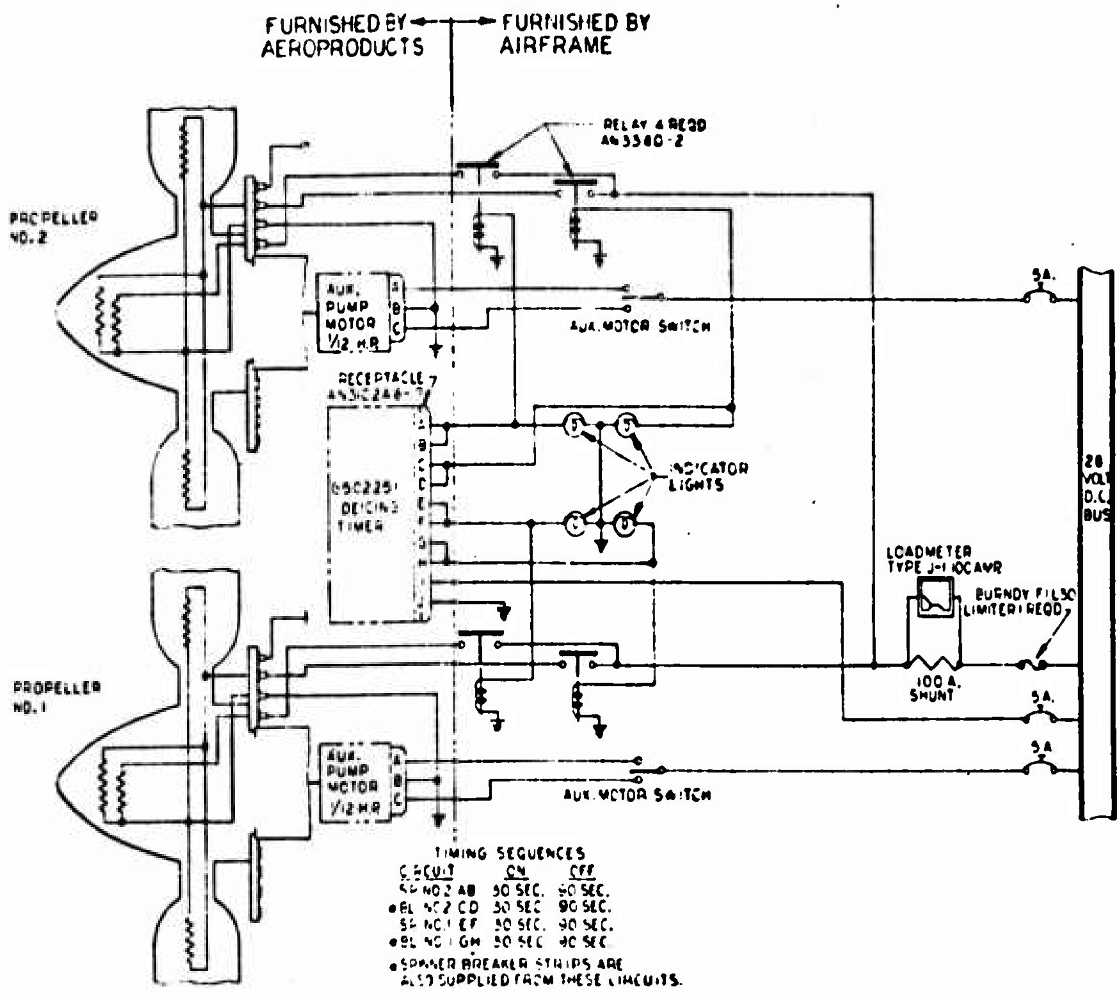

Figure 5. Electrical System Schematic for Twin Engine Installation

III. STRUCTURAL ANALYSIS

The data used in this section of the report are based upon testing accomplished at WADD and the contractor's plant. ER No. 1138, titled AF205F-272 Propeller Whirl Stand Tests at WADD, by E. B. Murray, concludes that (1) the propeller successfully completed all requirements of the testing program without failure or damage, (2) performance of the propeller demonstrates a good aerodynamic design, and (3) the vibratory and steady stress patterns obtained show that stress loads imposed are well within acceptable limits throughout the anticipated operating range of the propeller.

ANALYSIS

Stresses

The stresses created in the various critical parts of the propeller assembly are listed in Table 2. Allowable stresses for each of the parts are also listed.

The most severe loading condition for each component was used as the design criterion for the particular part. The loading conditions for the various components are as follows:

1. Pitch change mechanism—90 percent, 20,000 ft
2. Cruise stop—Cruise condition
3. Propeller hub—Overspeed condition
4. Blade retention—Overspeed condition
5. Propeller mounting—Maximum gyroscopic
6. Control rod—Maximum pump power

Retention Bearings

The take-off load on the retention bearings is 35,700 lb. The bearing load at an overspeed of 2715 rpm is 55,900 lb. The Brinell capacity of the bearings is 69,500 lb, which is the point of initial Brinelling. It has been determined through previous testing that the initial Brinelling encountered at the Brinell capacity does not hamper pitch change or weaken the retention system.

All parts in the hub mechanism not covered by this analysis are considered noncritical, and, based upon past experience, are considered safe within the limits normally called for in the aviation industry.

Propeller control forces for the AF 205F-272 propeller are shown in Table 3.

TABLE 2

Propeller Assembly Critical and Allowable Stresses

Part	Loading Condition	Type of Stress	Stress (Calculated) lb/in.^{2}	Stress* (Allowable) lb/in.^{2}
Pitch Change Mechanism	No. 1			
Blade Pins		Shear	5,470	35,000
Blade Pin Yoke		Shear	1,100	35,000
Yoke Threads		Shear	250	35,000
Torque Rod (Small end)		Axial tensile	15,000	65,000
Piston Head		Tensile	500	65,000
Feather Spring			50,000	120,000
Cruise Stop	No. 2			
Fingers		Axial Compression	1,400	65,000
Pins		Shear	20,000	35,000
Spring			20,000	120,000
Propeller Hub	No. 3			
Hub Flange		Shear	2,600	38,000
Hub Flange Bolts		Tensile	120,000	180,000
Hub Flange Hoop		Tensile	22,200	55,000
Hub Flange Bending		Tensile	12,100	55,000
Blade Retention	No. 4			
Clamp Lands		Shear	1,620	35,000
Clamp Bands		Hoop Tensile	22,500	65,000
Clamp Bolts		Tensile	46,000	180,000
Propeller Mounting	No. 5			
Mounting Bolts		Tensile	1,100	38,000
Mounting Flange		Tensile	3,000	40,000
Control Rod	No. 6	Torsional Shear	4,000	35,000

*These allowable stress values are consistent with previous testing experience on similar parts.

TABLE 3

Propeller Control Forces AF 205F-272

	Velocity (knots)	Altitude (ft)	SHP	Propeller RPM	β 75% Radius	Q_a in.-lb/blade	Q_b in.-lb/blade	(5500 lb at 45°) (for 2 CW) CWCF (in.-lb)
Take-off	0	SL	250	2057	16.1	+169	-1385	3010
	80	SL	250	2057	17.6	- 85	-1470	3240
	100	SL	250	2057	18.8	-188	-1600	3420
Climb	100	SL	250	2057	19.7	-191	-1475	3490
	100	5,000	250	2057	21.0	- 96	-1507	3685
Cruise 60%	140	SL	127	1543	29.2	-283	- 918	2650
60%	140	5,000	127	1543	29.9	-211	- 920	2685
60%	140	10,000	127	1543	30.9	-153	- 920	2740
60%	140	15,000	127	1543	31.5	-112	- 920	2780
90%	220	SL	183	1954	32.3	-717	-1470	4490
90%	250	20,000	183	2057	34.7	-325	-1630	5130
Windmill Dive	261	10,000	- 4	1748	36.6	-807	-1170	4160
	220	10,000	- 4	1954	33.6	-888	-1462	4990

	Blade Pin Radius (inches)	Blade Force on Rod (lb)	Spring Force (lb)	Total Rod Force (lb)	Rod Force Friction (lb)	Prop Thrust (lb)	Forward Gearbox Bearing Thrust (lb)	Decrease Pitch Pressure (psi)
Take-off	1.42	198	189	387	213	1023	386	76
	1.44	191	188	379	215	758	379	60
	1.45	29	188	217	217	622	307	50
Climb	1.45	95	188	283	217	628	345	
	1.45	330	187	517	217	628	111	
Cruise 60%	1.49	167	182	349	121	268	- 81	52
60%	1.49	190	182	372	121	268	-104	56
60%	1.50	396	180	576	121	268	-308	86
60%	1.50	478	180	658	121	268	-390	98
90%	1.50	78	180	258	197	205		39
90%	1.50	820	179	999	213	180	-819	150
Windmill Dive	1.50	137	178	315	158	- 1	-314	47
	1.50	193	179	372	197	- 2	-370	56

Blade section properties are given in Table 4.

TABLE 4

Blade Section Properties, 6505821 Blade

Radius	h	b	A	I_{min}	I_{max}	β
4.0	3.250	3.25	8.296	5.477	5.477	
5.0	2.323	3.46	6.039	2.063	4.073	77.29
6.0	1.912	3.98	5.494	1.276	4.450	74.18
7.0	1.648	4.71	5.610	0.944	6.503	71.10
8.0	1.454	5.52	5.879	0.778	9.792	68.02
9.0	1.299	6.24	5.962	0.615	13.205	64.99
10.0	1.168	6.77	5.826	0.486	15.292	61.88
11.0	1.056	7.00	5.461	0.374	15.316	58.84
12.0	0.958	7.00	4.948	0.280	13.878	55.76
15.0	0.741	7.00	3.828	0.133	10.740	48.26
18.0	0.601	7.00	3.105	0.073	8.713	43.32
21.0	0.508	7.00	2.624	0.046	7.365	39 70
24.0	0.445	7.00	2.302	0.032	6.461	36.78
30.0	0.361	7.00	1.864	0.018	5.231	32.18
36.0	0.296	7.00	1.531	0.011	4.294	28.70
42.0	0.238	7.00	1.230	0.006	3.446	25.82
45.0	0.210	7.00	1.085	0.004	3.038	24.50

Blade Weight

The weight of the blade can be obtained from the integration of the area curve. Allowing for tolerances, the actual blade weight is 15.23 pounds.

Centrifugal Force and Stresses

The total centrifugal force of the blade at the root end (r = 0.619) is 27,252 at 2057 rpm. The centrifugal stresses at the minimum cross section in the root at the point of retention is 3264 psi at the 1.827-in. r. The maximum centrifugal stress in the outboard portion of the blade is 6019 psi at the 21-in. r.

Thrust Bending Moment and Stress

The bending moment for the take-off thrust of 517.0 lb per blade at 2057 rpm is 7900 in.-lb at the point of retention on the blade shank (r = 1.827 in.) The bending stress at the minimum cross section in the shank is 2369 psi at the 1.827-in. r.

Maximum Steady Stresses

The maximum steady stress occurs at the 15-in. radius where the centrifugal stress is 5190 psi and the bending stress on the flat side is 5079 psi. The total combined tensile stress is 10, 269 psi at the 15-in. radius. The maximum steady stress in the minimum cross section of the shank is 5633 psi.

Centrifugal Twisting Moment

The centrifugal twisting moment, when the blade is operated at 2057 rpm with a blade angle of 30.55° at the 33-in. r, has a maximum value of -1629 in.-lb. The twisting moment at any other blade angle is,

$$Q_b = -1629 \sin 2 (\beta\ 33\text{-in. } r + 14.45°)$$

Blade Center of Gravity

The center of gravity of the blade is located 14.9 in. from the center of rotation.

Inflow Loading

The inflow loading has been computed for an aircraft similar to the L19. The maximum amplified loads for normal flight conditions occur at the high speed condition at low gross weight. The amplified forcing function per blade for this condition is 370 lb. This loading results in a vibratory bending moment at the blade root (r = 0.619 in.) of 8800 inch-pounds. The vibratory stress at the point of retention is 964 psi. Maximum vibratory stress on the camber side of the blade is ±5226 psi at the 15-inch radius.

Bending Frequencies

The natural bending frequencies obtained from digital computations for the 6505821 blade are as follows:

RPM	β 0.75 r/R	Flat cpm	Edge cpm
0	20	1255	
500	20	1419	
1100	20	1888	
1500	20	2253	
1800	20	2529	
2057	20	2763	5971
2057	40	2494	5981

The 2xP critical rpm is 670 at an operating blade angle of 20° at the 0.75 R.

Torsional Frequency

The 6505821 blade has a calculated torsional frequency of 165.5 cps at 2057 rpm.

Allowable Stresses

The allowable vibratory stresses for the various portions of a solid dural blade outboard of the 3-in. r have been established from numerous tests of dural blades. The following values have been used in the design of this blade:

Root Section: shot peened	
Continuous vibratory	± 6,500 psi
Intermittent vibratory	± 7,500 psi
Maximum steady stress	15,000 psi
Middle Section: shot peened	
Continuous vibratory	± 7,000 psi
Intermittent vibratory	± 8,000 psi
Maximum steady stress	15,000 psi

Inasmuch as the calculated inflow stresses are appreciably less than these limits, the blade is considered satisfactory for use with an accumulation of environmental damage on the surface outboard of the 12-in. radius. Inboard of this radius, the cuff will protect the dural blade.

IV. AERODYNAMIC DESIGN

A detailed analysis was conducted to determine the aerodynamic design for the AF 205F-277 Propeller for use with the Allison T63-A-1 turboprop engine. Since no specific airframe has been designated for this propulsion system, no design operating conditions were delineated. Consequently, the operating conditions utilized for analysis in the optimum study were based upon the schedule of desired performance, as outlined in the proposal request, and upon the engine operating parameters, as shown in Allison Engine Model Specification No. 470-A for the T63-A-1 engine. The design analysis leading to the final blade selection was based upon performance at climb and cruise conditions, along with available static thrust. The requirements of maximum structural integrity have been of constant consideration.

This section outlines the design methods used for final blade selection and for the flight performance data shown. The results of an optimized study leading to the final blade selection are presented, together with the aerodynamic characteristics of the blade. Also presented are the performance capabilities of the propeller at various flight conditions.

The final blade selection (Aeroproducts 6505821 type) is a blade of 7-ft, 6-in. diameter and 7-in. chord, with an integrated lift coefficient of 0.5. The thickness ratio is compatible with structural and performance requirements. The complete aerodynamic description of the blade is shown in Figure 6.

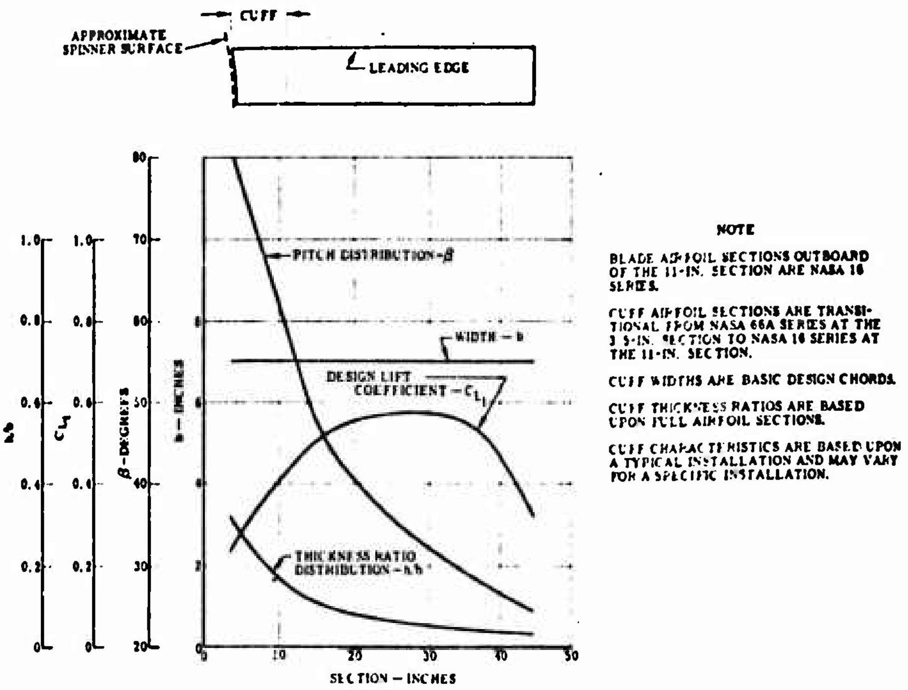

Figure 6. Blade Characteristics of Blade Model 6505821

The methods employed in the analysis to select the propeller and to describe its performance capabilities with the T63-A-1 turboprop engine have been employed by Aeroproducts over past years in the development of high performance turbo-propellers. Reliable wind tunnel tests of propellers designed by these methods of analysis have demonstrated that the predicted performance so obtained is in accordance with experimental data.

DISCUSSION

For purposes of evaluation, the optimum studies were based upon propeller performance at the following selected flight conditions:

Condition	Altitude (ft)	SHP	Prop RPM	Velocity (TAS - Kn)
Take-Off	SL	250	2057	0
Cruise	15,000	212	2057	200
Climb	SL	212	2057	91

The design analysis was directed toward determining a propeller capable of producing a minimum of 1000 lb of thrust at the static condition with compatibly high efficiency at the climb and cruise conditions.

This section of the design study presents the methods employed to analyze the propeller design parameters aerodynamically, the results of which ensure optimum selections for the primary flight considerations. Throughout the analysis, the Aeroproducts strip method of analysis has been used in determining flight efficiencies.

The take-off thrust analysis has been based upon data taken from actual whirl tests of the propeller on WADD test stands.

The variation of the flow field as derived for the 200-knot design cruise condition is shown in Figure 7. If the configuration of a specific application dictates changes in pitch distribution in order to obtain a better distribution of the flow field, such minor modifications can be made without materially affecting the blade structure.

The velocities used in determining the proper advance ratios for calculating the design flight propeller efficiencies have been derived from the respective velocity ratios through the propeller plane. The local forward Mach number through the propeller plane at each station is equal to the free stream forward Mach number multiplied by the respective velocity ratio (V_L/V_o). The average Mach number through the propeller plane is calculated from the following formula:

$$M_{average} = \frac{1}{A} \int_{spinner}^{tip} M_{local}\, dA \quad \therefore \quad \begin{array}{l} dA = 2\pi r\, dr \\ A = \text{annular swept area} \end{array}$$

Upon integrating this formula within the limits of the propeller radius from spinner to tip, the average Mach number can be determined. This average forward Mach number has then been used to determine the velocities for the proper advance ratios for calculating propeller efficiencies.

Optimized design studies were conducted for the cruise and climb conditions as noted. To obtain a high level of efficiency at the cruise and climb conditions, consideration had to be given to minimizing the effects of compressibility. From a performance standpoint, this dictated the use of relatively thin sections coupled with low-to-medium values of camber. Section thickness ratios were made as low as possible, compatible with structural requirements of thickness ratio to provide high enough natural torsional and flatwise frequencies.

Optimum aerodynamic load distributions for minimum induced losses were determined for the two design conditions noted. From these optimum load distributions (in terms of blade solidity and operating lift coefficient), a propeller with minimum profile losses can be designed. In order to design the blade for minimum profile loss, each section of the blade has to operate at the C_L for maximum L/D ratio for that section. The blade planform that normally results from this procedure is usually compromised in the direction of constant chord, which helps to provide a relatively high level of take-off thrust, with a negligible loss in flight efficiency resulting from the compromise. As a result, only constant chord blades were investigated in this study.

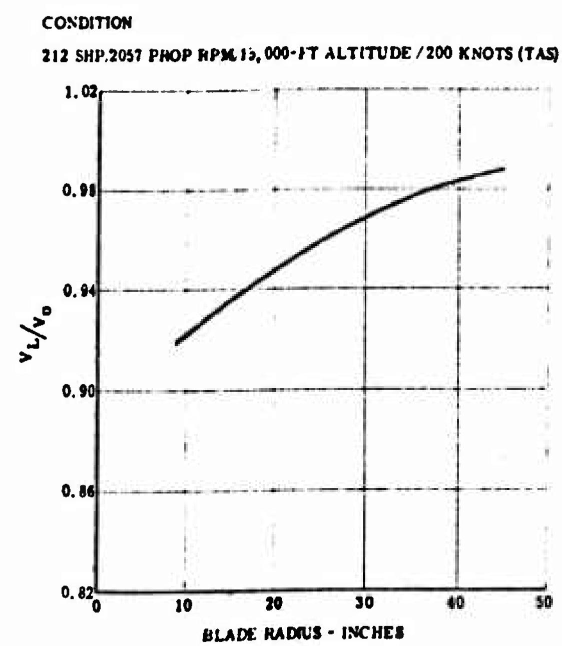

Figure 7. Variation of Flow Field as Derived for the 200-Knot Design Cruise Condition

The camber distributions shown in Figure 8 on an r/R basis were used in the design study and are cambers based upon optimum load distributions. The curves are identified by the integrated design lift coefficient which is identified as:

$$\text{Int. } C_{L_i} = 4 \int_{r/R\, =\, \text{spinner}}^{r/R\, =\, 1.0} C_{L_i}\, (r/R)^3\, dr/R$$

In order to show the effect of operating a given chord at nonoptimum cambers, the optimum induced load distribution previously determined is investigated over a selected range of blade chords for each of the integrated camber distributions. The variation of chord and camber with lines of constant flight efficiency levels for the two design conditions are shown in Figures 9 and 10.

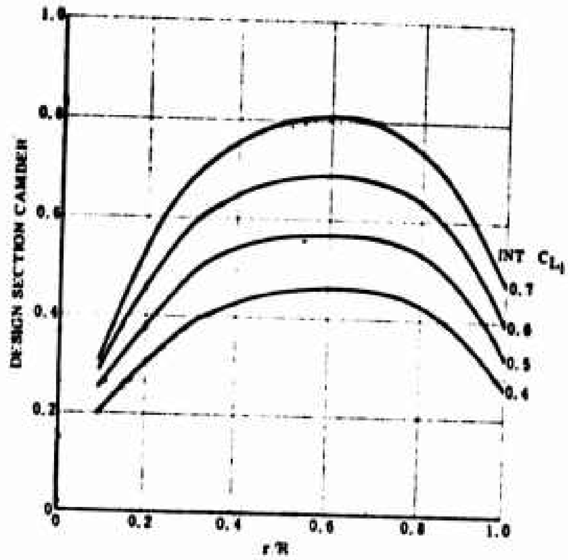

Figure 8. Chamber Distribution vs r/R for Constant Integrated Design Lift Coefficients Used in the Design Optimum Analysis Study

"Island Efficiency Charts" combining the variations of chord and integrated blade camber with the parameter of lines of constant propeller efficiency (shown in Figures 9 and 10) were plotted in order to evaluate properly the effects of operation at nonoptimum integrated cambers for the range of blade chords investigated. As can be seen in Figures 9 and 10, performance is affected by changes in either chord or integrated camber. The optimum efficiency for each chord investigated in this study would be on a line drawn through the peak point of the efficiency lines. However, peak efficiency parameters for the design cruise and climb conditions have to be compatible with the thrust parameters at the take-off regime. In order to measure the degree of aerodynamic compatibility, propeller thrusts at zero knots were determined for the same chord and camber ranges covered in the cruise and climb studies noted in the design specification. The static thrust data is plotted in both Figures 9 and 10, along with the flight efficiency results.

An examination of the studies at the climb and cruise conditions, together with the available take-off thrust, resolved into a choice of the chord and camber combination yielding the highest level of climb and cruise efficiency, and still providing approximately four pounds of thrust per shaft horsepower statically. At the same time, the blade design parameters must stay within the bounds prescribed by structural requirements. The chord choice is dictated primarily by static thrust level and by structural requirements as the chord, coupled with the thickness ratio, controls blade torsional frequency to a large extent. Chord choice also has a distinct bearing on final propeller weight. The controlling principle for camber selection is the level of efficiency at the climb and cruise conditions and the level of take-off thrust. The final propeller blade selection representing the best compromise for these propeller requirements utilizes a blade chord of 7 in. and an integrated lift coefficient of 0.5.

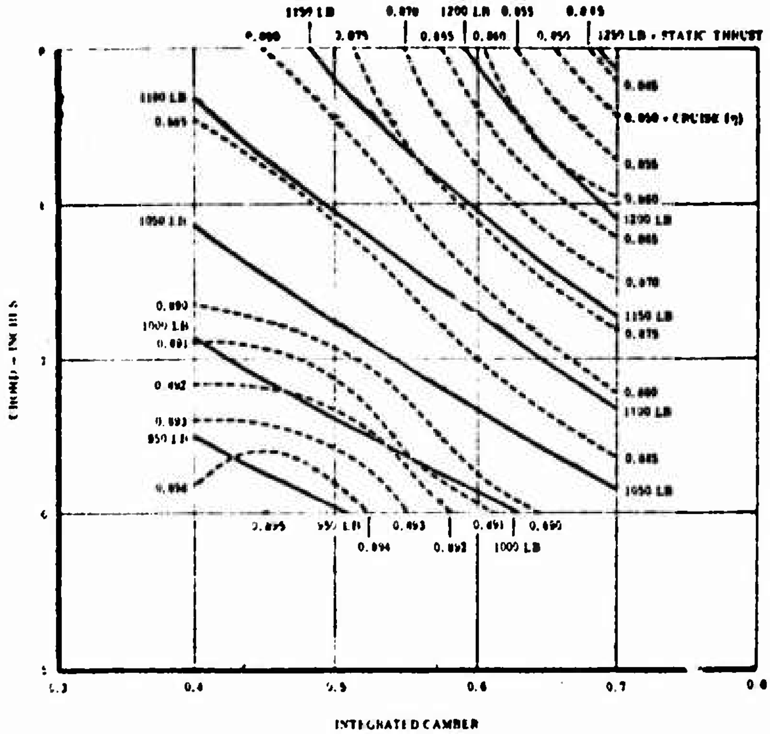

Figure 9. Variation of Chord and Camber with Lines of Constant Flight Efficiency Levels for Design Cruise Condition

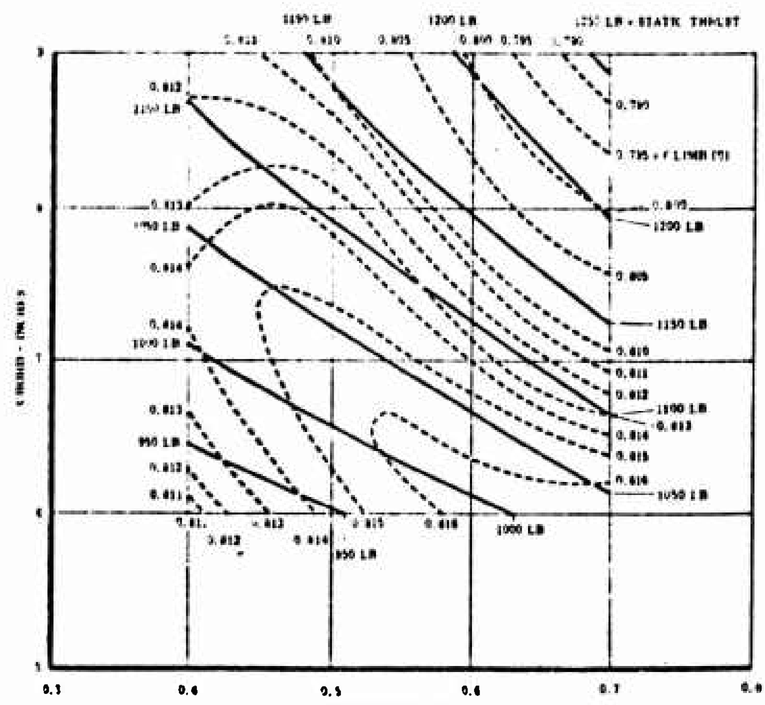

Figure 10. Variation of Chord and Camber with Lines of Constant Flight Efficiency Levels for Design Climb Condition

The spinner contour selected for this installation was based upon extensive NASA testing of three basic spinner types—the series-1 shape, a conical, and a modified conical. For annular-type engine inlets, the pure conical spinner is usually superior, since ram recovery in the absence of a boundary layer bleed is best affected by the pressure envelope of the conical spinner. The conical spinner has a higher drag level than the series-1 type. For engine installations which have their inlets far removed from the spinner flow-field, the series-1 shape is usually selected, as the spinner flow does not contribute to the engine ram recovery and the series-1 shape provides the smallest drag. For engines such as the T63 and T56, which have isolated inlets near the spinner flow-field, the best compromise is a modified conical type used in conjunction with an inlet boundary-layer bleed. It has been assumed that installations utilizing the T63-A-1 engine will provide a proper boundary-layer bleed; consequently, the spinner shape selected is the modified-conical type. This spinner design provides the maximum of engine inlet ram outside the spinner boundary layer together with the lowest compatible drag values.

The decision to equip the propeller with cuffs was based upon three factors. Since each of these factors pointed up the gains to be made with cuffs, the propeller will be supplied with blade cuffs. The three factors are as follows:

1. Based upon previous wind tunnel testing (NASA, Aeroproducts, etc), the highest ram recoveries to be expected for a propeller with round shanks and a transition region outside the spinner lie in the 88-90 percent region. As shown in the engine specification, ram recovery levels of 90 percent reduce available engine horsepower from 25 to 35 shp. Since a properly designed cuff can provide up to 102 percent ram recovery (based upon wind tunnel testing conducted by Aeroproducts), an additional 5 to 7 shp above that shown in the engine specification for 100 percent ram recovery may be expected. The use of a properly designed cuff can, therefore, restore from 30 to 42 shp above the 90 percent ram recovery level obtained by the typical blade shape without cuffs. Aeroproducts has recently participated in two extensive cuff design parameter wind tunnel studies; the results of these studies have been applied to the cuff design for the AF 205F-272 Propeller.

2. A second item of importance affecting the decision of whether to provide cuffs was the magnitude by which the level of propeller efficiency was affected with and without a properly designed blade cuff. Two performance analyses were conducted at the design cruise point; one analysis was for a blade with a properly designed cuff, the second for a blade with a round shank at the spinner, and transition area outboard of the round shank. The results of the study showed the round shank blade to be inferior to the cuffed blade by 6.5 percent in propeller efficiency. The reason for the lowered efficiency lies in the high C_D values for the round section (very low Reynolds number) which adversely affect the station-wise incremental thrust coefficients without materially altering the incremental torque coefficients. The cuffed blade, by retaining the

proper angle of attack and thickness ratio, maintains good values of the incremental thrust coefficient. Consequently, the cuffed blade is superior to the uncuffed blade by the amount shown.

3. The presence of the cuff makes blade deicing easier in the inlet region, as against having a transition section in this region.

The preliminary characteristics for the 6505821 blade are shown in the blade characteristics sheet of Figure 5. The blade and cuff outlines are shown in the planform view. Listed on the characteristics sheet are types of airfoil sections to be used for the blade and cuff structures.

The NASA 16, 64, 65, and 66 series airfoils are the most suitable for propeller applications. They were designed to have high critical Mach numbers by developing a thickness distribution against chord length which resulted in very low induced velocities. In propeller design, the 64, 65, and 66 series sections are considered when the relatively thick inboard propeller sections will be operating at high lift coefficients at moderate Mach numbers. Consideration was given to keeping the cuff thickness ratios as low as possible, as past investigations by Aeroproducts have shown that the utilization of thin sections in this region will yield ram recovery ratios of a satisfactorily high level. Experience has shown that a limited amount of increased twist in the cuff sections results in better ram recovery for this region of the propeller; therefore, these sections should be designed for operation at moderate to high lift coefficients. For the low Reynolds numbers at which these sections will be operating for this application, the section drag coefficients are lowest for the 66 series airfoils, according to NASA experimental data. In view of this factor, the 66 series airfoils were then selected for the cuff sections for the 6505821 blade. For manufacturing reasons, the 66A sections are used in order to remove the cusp from the trailing edge region. NASA performance data show the 66 and 66A series airfoils to differ insignificantly.

In the selection of airfoil series for the blade section portion of the 6505821 blade, the 16 series airfoils were favored. A comparison of the airfoil ordinates of the 16 and 66A series sections shows that they are so nearly identical that performance characteristics are negligibly different. This conclusion has been verified from section data derived experimentally at Langley, Ames, and the Boeing wind tunnels which show that no consistent advantage can be gained by either airfoil (when comparing lift/drag ratios and critical Mach numbers) except perhaps, at thickness ratios of less than 5 percent when the 16 series sections appear to have slightly higher critical Mach numbers. At thickness ratios of 12 percent or better, the 66A series airfoils have slightly higher critical Mach numbers. Since approximately 50 percent of the blade radius is at a thickness ratio of 12 percent or less, with tip sections at 5 percent or less in the region of the highest section Mach numbers, it is a reasonable choice to select the 16 series sections for the propeller blade portion.

The pitch distribution for the proposed blade was determined for the design cruise condition. The optimum pitch distribution for the two component blade parts was derived from the optimum study for the design cruise condition and modified in the cuff regions in order to improve the ram recovery characteristics. The pitch in the cuff region is increased somewhat from optimum loading conditions, based upon the results of extensive Aeroproducts wind tunnel testing on cuff configurations at compatible operating conditions. The pitch angles shown on the blade characteristics sheet (Figure 5) are the actual operating angles for the specific components of the blade. The twist of the blade portion beneath the cuff need only be compatible with the cuff component.

The performance for the AF 205F-272 Propeller with two Aeroproducts Type 6505821 Blades is shown in Table 5 for several given operating conditions. The 1xP loadings for critical flight conditions are shown in Table 6.

CONCLUSIONS

From the detailed analysis conducted to determine a satisfactory propeller installation for the Allison T63-A-1 turboprop engine, it can be concluded that a two-blade, 7.5-ft diameter propeller having a chord of 7 in., an activity factor of 121, and an integrated design lift coefficient of 0.50 is the best compromise selection. The propeller configuration selected is structurally and aerodynamically compatible.

TABLE 5

Performance Data---Two Aeroproducts Type 6505821 Blades

Condition	True Airspeed (kn)	Altitude (ft)	Power Setting	Power (shp)	Propeller RPM	Thrust (lb) or Efficiency
Take-off Std Day 59°F	0	SL	Military	250	2057	1110
	100		Military	250	2057	562
Take-off Hot Day 90°F	0	SL	Military	250	2057	1055
	100		Military	250	2057	578
Cruise	250	SL	Military	250	2057	0.878
	220	SL	Normal	212	2057	0.872
	200	SL	95% Normal	202	1954	0.885
	180	SL	90% Normal	191	1850	0.884
	150	SL	75% Normal	159	1748	0.883
	100	SL	60% Normal	127	1543	0.853
Cruise	250	5,000	Military	250	2057	0.883
	220	5,000	Normal	212	2057	0.880
	200	5,000	95% Normal	202	1954	0.891
	180	5,000	90% Normal	191	1850	0.887
	150	5,000	75% Normal	159	1748	0.883
	100	5,000	60% Normal	127	1543	0.843
Cruise	250	10,000	Military	250	2057	0.871
	220	10,000	Normal	212	2057	0.838
	200	10,000	95% Normal	202	1954	0.891
	180	10,000	90% Normal	191	1850	0.888
	150	10,000	75% Normal	159	1748	0.878
	100	10,000	60% Normal	127	1543	0.828
Cruise	250	15,000	Military	246	2057	0.895
	220	15,000	Normal	212	2057	0.891
	200	15,000	95% Normal	202	1954	0.892
	180	15,000	90% Normal	191	1850	0.883
	150	15,000	75% Normal	159	1748	0.866
	100	15,000	60% Normal	127	1543	0.798
Cruise	250	20,000	Military	204	2057	0.896
	220	20,000	Normal	183	2057	0.889
	200	20,000	95% Normal	174	1954	0.887
	180	20,000	90% Normal	165	1850	0.883
	150	20,000	75% Normal	137	1748	0.857
	100	20,000	60% Normal	110	1543	0.797
Cruise	250	25,000	Military	169	2057	0.894
	220	25,000	Normal	154	2057	0.888
	200	25,000	95% Normal	146	1954	0.889
	180	25,000	90% Normal	149	1850	0.884
	150	25,000	75% Normal	116	1748	0.857
	100	25,000	60% Normal	92	1543	0.789

TABLE 6

1xP Loadings for Critical Flight Conditions

Condition	Load Factor (g's)	A_q (deg-lb/ft^2)	Forcing Function (lb)	Amplification Factor	Shaft Shear Force (lb)	Shaft Moment (in.-lb)	Flight Condition
Climb at 91 kn IAS, Maximum G. W.	1.0	300	64	2.1	23	1900	Normal
Cruise at 250 kn IAS, Minimum G. W.	1.0	800	137	2.7	91	2820	Normal
Pull-Up at 250 kn	2.5	1020	174	2.7	115	3600	Maneuver
20° Yaw at 100 kn	1.0	1150	244	2.2	89	6500	Maneuver
Negative Load Factor at 250 kn	-1.0	1040	178	2.7	118	3680	Maneuver
45° Dive at 250 kn	0.707	850	145	2.7	96	3000	Maneuver
90° Dive at 250 kn	0	865	148	2.7	98	3060	Maneuver

V. WEIGHT BREAKDOWN ANALYSIS - AF205-272 PROPELLER

The following weight analysis of the Aeroproducts AF 205F-272 Propeller is based on a twin engine installation using one-half of the deicing timer weight. In summary, the original Aeroproducts estimated weight of 69 pounds has increased by 11.34 pounds as shown in the following:

Estimated Propeller Weight	69 lb	
Spinner Plus Ice Control System	11.1 lb	
Propeller Oil (2 Pints, MIL-L-7808)	1.8 lb	
TOTAL		81.9 lb
Increased Propeller Weight (Measured)	11.34 lb	
INCREASED TOTAL		93.24 lb

The weight increase over the proposed propeller is attributed to the following:

	Weight Originally (lb)	Weight Now (lb)	Change (lb)
1. Heavier flyweights---because of a spinner diameter decrease, the flyweights had to be relocated closer to the center of rotation.	4.0	8.0	+4.0
2. Heavier hub body---due to the decision to make both halves of the split hub body identical from a cost standpoint.	8.68	10.5	+1.82
3. The Control Unit was changed from magnesium to aluminum for strength reasons and altered to clear the other engine-mounted accessories.	3.42	6.83	+3.41

	Weight Originally (lb)	Weight Now (lb)	Change (lb)
4. Feathering Spring assembly had to be redesigned and a housing provided when the Control Unit was relocated to the accessory section.	—	2.11	+2.11
TOTAL WEIGHT INCREASE			+11.34

VI. MATERIAL SECTION

No work has been accomplished as defined in paragraph 2 of Table LXXV.

Allison Division, General Motors Corporation

FINAL DESIGN ANALYSIS OF AF 205F-272 PART I. PROPELLER AT TIME OF FIRST RUN. 31 January 1961. 25 p. incl. illus. (Project No. 3138, Task No. 30548) (WADD-TR-61-55 Pt I) (Contract AF 33(600)-39928)

Presented herein are design analyses, propeller description, structural analysis (including performance considerations), aerodynamic design analysis, and a weight breakdown of the AF 205F-272 propeller configuration at the time of the first run.

This report is intended to present information which will lend itself directly to the final design configuration of a controllable pitch propeller, as prescribed in the subject contract.

1. Summary of Propeller Response at the Time of the First Run
2. Propeller Description
3. Structural Analysis
4. Aerodynamic Design
5. Weight Breakdown Analysis-AF 205F-272 Propeller
6. Material Section

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